APPENDIX C
MODEL/EQUATIONS FOR ESTIMATING TIER 1 AND TIER 2A TARGET LEVELS WITHIN THE DCRBCA PROCESS

The symbols used in the equations are all defined with their units. Also, symbols are consistent with those used in Tables 5-4 and 5-5; the DCRBCA computational software and report forms.

INDOOR INHALATION OF VAPOR EMISSIONS

<u>Carcinogenic effects</u>

$$RBTL_{ai} = \frac{TR \times BW \times AT_c \times 365}{IR_{ai} \times ET_{in} \times ED \times EF \times SF_i}$$

<u>Non-carcinogenic effects</u>

$$RBTL_{ai} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{IR_{ai} \times ET_{in} \times ED \times EF}$$

Source: RAGS, Vol. I, 1989, p. 6-44

where:

$RBTL_{ai}$	=	Risk-based target level in indoor air [mg/m^3]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens[years]
AT_{nc}	=	Averaging time for non-carcinogens[years]
IR_{ai}	=	Indoor inhalation rate [m^3/hr]
ET_{in}	=	Indoor Exposure time [hr/day]
ED	=	Exposure duration [years]
EF	=	Exposure frequency [days/year]
RfD_i	=	The chemical-specific inhalation reference dose [mg/(kg-day)]
SF_i	=	The chemical-specific inhalation cancer slope or potency factor [mg/(kg-day)]$^{-1}$

OUTDOOR INHALATION OF VAPOR EMISSIONS

<u>Carcinogenic effects</u>

$$RBTL_{ao} = \frac{TR \times BW \times AT_c \times 365}{IR_{ao} \times ET_{out} \times ED \times EF \times SF_i}$$

<u>Non-carcinogenic effects</u>

$$RBTL_{ao} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{IR_{ao} \times ET_{out} \times ED \times EF}$$

Source: RAGS, Vol. I, 1989, p. 6-44

Where:

$RBTL_{ao}$	=	Risk-based target level in outdoor air [mg/m^3]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens[years]
AT_{nc}	=	Averaging time for non-carcinogens[years]
IR_{ao}	=	Outdoor inhalation rate [m^3/hr]
ET_{out}	=	Outdoor Exposure time [hr/day]
ED	=	Exposure duration [years]
EF	=	Exposure frequency [days/year]
RfD_i	=	The chemical-specific inhalation reference dose [mg/(kg-day)]
SF_i	=	The chemical-specific inhalation cancer slope or potency factor [mg/(kg-day)]$^{-1}$

DIRECT INGESTION OF GROUNDWATER (ONLY FOR CHEMICALS WITHOUT DC WATER QUALITY STANDARDS)	
Carcinogenic effects $$RBTL_w = \frac{TR \times BW \times AT_c \times 365}{IRW \times ED \times EF \times SF_o}$$ Non-carcinogenic effects $$RBTL_w = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_o}{IR_W \times ED \times EF}$$ Source: RAGS, Vol. I, 1989, p. 6-35	Where: $RBTL_w$ = Risk-based target level for ingestion of groundwater [mg/L-H_2O] TR = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-] THQ = Target hazard quotient for individual constituents [-] BW = Body weight [kg] AT_c = Averaging time for carcinogens[years] AT_{nc} = Averaging time for non-carcinogens[years] IR_W = Water ingestion rate [L/day] ED = Exposure duration [years] EF = Exposure frequency [days/year] RfD_o = The chemical-specific oral reference dose [mg/(kg-day)] SF_o = The chemical-specific oral cancer slope or potency factor [mg/(kg-day)]$^{-1}$

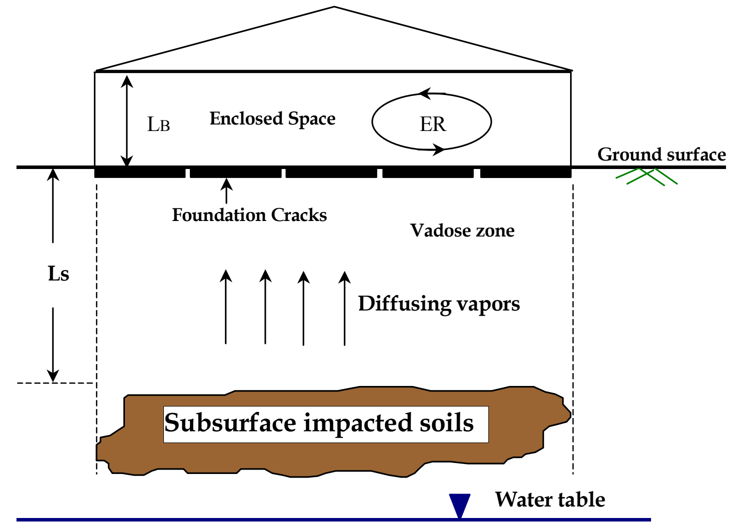
SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

$$RBTL_{si} = \frac{RBTL_{ai}}{VF_{sesp}}$$

where:

$RBTL_{si}$	=	Risk-based target level for indoor inhalation of vapors from subsurface soils [mg/kg-soil]
$RBTL_{ai}$	=	Risk-based target level for indoor inhalation of air [mg/m^3-air]
VF_{sesp}	=	Volatilization factor from subsurface soil to indoor (enclosed space) air [(mg/m^3-air)/(mg/kg-soil)]

Source: ASTM E1739-95



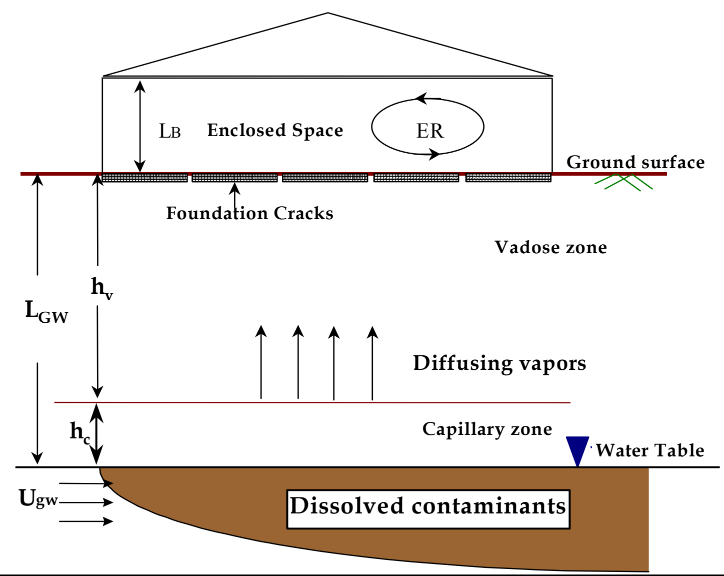
GROUNDWATER CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

$$RBTL_{wi} = \frac{RBTL_{ai}}{VF_{wesp}}$$

where:

$RBTL_{wi}$	=	Risk-based target level for indoor inhalation of vapors from groundwater [mg/L-H_2O]
$RBTL_{ai}$	=	Risk-based target level for indoor inhalation of air (mg/m^3-air)
VF_{wesp}	=	Volatilization factor from groundwater to indoor (enclosed space) air [(mg/m^3-air)/(mg/L-H_2O)]

Source: ASTM E1739-95



INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT AND INGESTION OF CHEMICALS IN SURFICIAL SOIL

Carcinogenic effects

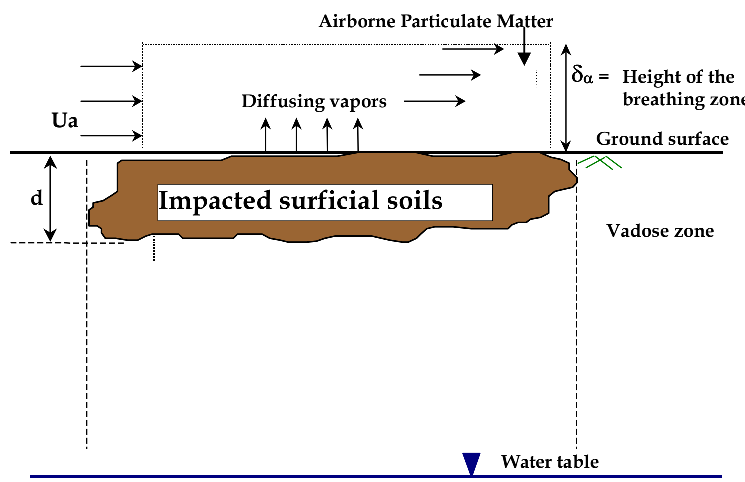
$$RBTL_{SS}=\frac{TR\times BW\times AT_c\times 365}{EF\times ED\times[(SF_o\times 10^{-6}\times(IR_{soil}\times RAF_o+SA\times M\times RAF_d))+(SF_i\times IR_{ao}\times ET_{out}\times(VF_{SS}+VF_p))]}$$

Non-carcinogenic effects

$$RBTL_{SS}=\frac{THQ\times BW\times AT_{nc}\times 365}{EF\times ED\times\left[\frac{10^{-6}\times(IR_{soil}\times RAF_o+SA\times M\times RAF_d)}{RfD_o}+\frac{(24\times IR_{ao}\times(VF_{ss}+VF_p))}{RfD_i}\right]}$$

where:

$RBTL_{ss}$	=	Risk-based target level in surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [years]
AT_{nc}	=	Averaging time for non-carcinogens [years]
ED	=	Exposure duration [years]
EF	=	Exposure frequency [days/year]
IR_{soil}	=	Soil ingestion rate [mg/day]
RAF_o	=	Oral relative absorption factor [-]
SA	=	Skin surface area [cm^2/day]
M	=	Soil to skin adherence factor [mg/cm^2]
RAF_d	=	Dermal relative absorption factor [-]
IR_{ao}	=	Outdoor inhalation rate [m^3/hr]
ET_{out}	=	Outdoor Exposure time [hr/day]
SF_o	=	Oral cancer slope factor [$(mg/kg\text{-}day)^{-1}$]
SF_i	=	Inhalation cancer slope factor [$(mg/kg\text{-}day)^{-1}$]
RfD_o	=	The chemical-specific oral reference dose [(mg/kg-day)]
RfD_i	=	The chemical-specific inhalation reference dose [(mg/kg-day)]
VF_p	=	Volatilization factor of particulates [(mg/m^3-air)/(mg/kg-soil)]
VF_{ss}	=	Volatilization factor from surficial soil [(mg/m^3-air)/(mg/kg-soil)]



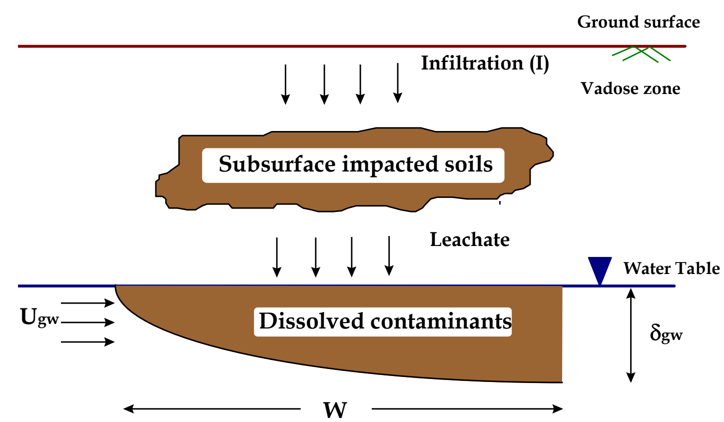
Source: ASTM E1739-95

SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF LEACHING TO GROUNDWATER

$$RBTL_{SL} = \frac{RBTL_w}{LF_{SW}}$$

where:

$RBTL_{SL}$	=	Risk-based target level for leaching to groundwater from subsurface soil [mg/kg-soil]
$RBTL_w$	=	Risk-based target level for ingestion of groundwater [mg/L-H_2O]
LF_{SW}	=	Leaching Factor (from subsurface soil to groundwater) [(mg/L-H_2O)/(mg/kg-soil)]



Source: ASTM E1739-95

VOLATILIZATION FACTORS

VF_{wesp}: Volatilization factor from groundwater to indoor (enclosed space) air [(mg/m^3-air)/(mg/L-H_2O)]	VF_{wamb}: Volatilization factor from groundwater to outdoor (ambient) air [(mg/m^3-air)/(mg/L-H_2O)] **- For Construction Worker Only**
$$VF_{wesp} = \frac{H \times \left[\frac{D_{ws}^{eff} / L_{GW}}{ER \times L_B}\right]}{1 + \left[\frac{D_{ws}^{eff} / L_{GW}}{ER \times L_B}\right] + \left[\frac{D_{ws}^{eff} / L_{GW}}{\left(D_{crack}^{eff} / L_{crack}\right) \times h}\right]} \times 10^3$$ where: H = Chemical specific Henry's Law constant[(mg/cm^3-air)/(mg/cm^3-H_2O)] L_{GW} = Depth to groundwater [cm] L_B = Enclosed space volume/infiltration area ratio [cm] L_{crack} = Enclosed space foundation or wall thickness [cm] ER = Enclosed space air exchange rate [1/s] D_{ws}^{eff} = Effective diffusion coefficient between groundwater and soil surface [cm^2/s] D_{crack}^{eff} = Effective diffusion coefficient through foundation cracks [cm^2/s] h = Areal fraction of cracks in foundation and/or walls [cm^2-cracks/ cm^2-total area] 10^3 = Conversion factor [L/m^3] Source: ASTM E1739-95	$$VF_{wamb} = \frac{H}{1 + \left[\frac{U_a \times \delta_a \times L_{GW}}{W_{ga} \times D_{ws}^{eff}}\right]} \times 10^3$$ where: H = Chemical-specific Henry's Law constant [(mg/cm^3-air)/(mg/cm^3-H_2O)] U_a = Wind speed at δ_a above ground surface [cm/s] δ_a = Breathing zone height [cm] L_{GW} = Depth to groundwater [cm] W_{ga} = Length of groundwater source area parallel to wind direction [cm] D_{ws}^{eff} = Effective diffusion coefficient between groundwater and soil surface [cm^2/s] 10^3 = Conversion factor [L/m^3] Source: ASTM E1739-95

VF_{sesp} : Volatilization factor from subsurface soil to indoor (enclosed space) air [(mg/m^3-air)/(mg/kg-soil)]	
$$VF_{sesp} = \frac{\dfrac{H \times \rho_s}{[\theta_{ws} + (K_s \times \rho_s) + (H \times \theta_{as})]} \times \left[\dfrac{D_s^{eff} / L_s}{ER \times L_B}\right]}{1 + \left[\dfrac{D_s^{eff} / L_s}{ER \times L_B}\right] + \left[\dfrac{D_s^{eff} / L_s}{(D_{crack}^{eff} / L_{crack}) \times h}\right]} \times 10^3$$ Source: ASTM E1739-95	where: H = Chemical specific Henry's Law constant [(mg/cm^3-air)/ (mg/cm^3-H_2O)] ρ_s = Dry soil bulk density [g-soil/cm^3-soil] θ_{ws} = Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3-soil] K_s = $f_{oc} \times K_{oc}$ = Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm^3-H_2O/g-soil] θ_{as} = Volumetric air content in vadose zone soils [cm^3-air/cm^3-soil] L_s = Depth to subsurface soil sources [cm] L_B = Enclosed space volume/infiltration area ratio [cm] L_{crack} = Enclosed space foundation or wall thickness [cm] ER = Enclosed space air exchange rate [1/s] D_s^{eff} = Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s] D_{crack}^{eff} = Effective diffusion coefficient through foundation cracks [cm^2/s] h = Areal fraction of cracks in foundation and/or walls [cm^2-cracks/ cm^2-total area] 10^3 = Conversion factor [(cm^3-kg)/(m^3-g)]

VF_{ss}: Volatilization factor from surficial soil [(mg/m^3-air)/(mg/kg-soil)]

*** *choose the smaller of the two* ***

$$VF_{ss} = \frac{2 \times W_a \times \rho_s}{U_a \times \delta_a} \times \sqrt{\frac{D_s^{eff} \times H}{\pi \times [\theta_{ws} + (K_s \times \rho_s) + (H \times \theta_{as})] \times \tau}} \times 10^3$$

where:

W_a	=	Length of soil source area parallel to wind direction [cm]
ρ_s	=	Dry soil bulk density [g-soil/cm^3-soil]
U_a	=	Wind speed at δ_a above ground [cm/s]
δ_a	=	Breathing zone height [cm]
D_s^{eff}	=	Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]
H	=	Chemical-specific Henry's Law constant [(mg/cm^3-air)/ (mg/cm^3-H_2O)]
θ_{ws}	=	Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3- soil]
K_s	=	$f_{oc} \times K_{oc}$
	=	Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm^3-H_2O/g-soil]
θ_{as}	=	Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
τ	=	Averaging time for vapor flux [s]
	=	*ED (yr) × 365 (day/yr) × 86400 (sec/day)*
10^3	=	Conversion factor [(cm^3-kg)/(m^3-g)]

Source: ASTM E1739-95

$$VF_{ss} = \frac{W_a \times \rho_s \times d}{U_a \times \delta_a \times \tau} \times 10^3$$

where:

W_a	=	Length of soil source area parallel to wind direction [cm]
ρ_s	=	Dry soil bulk density [g-soil/cm^3-soil]
d	=	Depth to base of surficial soil zone [cm]
U_a	=	Wind speed at δ_a above ground surface [cm/s]
δ_a	=	Breathing zone height [cm]
τ	=	Averaging time for vapor flux [s]
	=	*ED (yr) × 365 (day/yr) × 86400 (sec/day)*
10^3	=	Conversion factor [(cm^3-kg)/(m^3-g)]

Source: ASTM E1739-95

VF_p : Delivery of particulate chemicals from soil to air [(mg/m^3-air)/(mg/kg-soil)]

$$VF_p = \frac{P_e \times W_a}{U_a \times \delta_a} \times 10^3$$

where:

P_e	=	Particulate emission rate [g-soil/cm^2-sec]
W_a	=	Length of soil source area parallel to wind direction [cm]
U_a	=	Wind speed at δ_a above ground surface [cm/s]
δ_a	=	Breathing zone height [cm]
10^3	=	Conversion factor [(cm^3-kg)/(m^3-g)]

Source: ASTM E1739-95

EFFECTIVE DIFFUSION COEFFICIENTS

D_s^{eff} : effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]

$$D_s^{eff} = D^a \times \frac{\theta_{as}^{3.33}}{\theta_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{\theta_{ws}^{3.33}}{\theta_T^{2.0}}$$

where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{as}	=	Volumetric air content in vadose zone [cm^3-air/cm^3-soil]
θ_{ws}	=	Volumetric water content in vadose zone [cm^3-H_2O/cm^3-soil]
θ_T	=	Total soil porosity in the impacted zone [cm^3/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [(mg/cm^3-air)/(mg/cm^3-H_2O)]

D_{ws}^{eff} : effective diffusion coefficient between groundwater and surface soil [cm^2/s]

$$D_{ws}^{eff} = (h_{cap} + h_v) \times \left[\frac{h_{cap}}{D_{cap}^{eff}} + \frac{h_v}{D_s^{eff}} \right]^{-1}$$

where:

h_{cap}	=	Thickness of capillary fringe [cm]
h_v	=	Thickness of vadose zone [cm]
D_{cap}^{eff}	=	Effective diffusion coefficient through capillary fringe [cm^2/s]
D_s^{eff}	=	Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]

D_{cap}^{eff} : effective diffusion coefficient for the capillary fringe [cm^2/s]

$$D_{cap}^{eff} = D^a \times \frac{\theta_{acap}^{3.33}}{\theta_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{\theta_{wcap}^{3.33}}{\theta_T^{2.0}}$$

where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{acap}	=	Volumetric air content in capillary fringe soils [cm^3-air/cm^3-soil]
θ_{wcap}	=	Volumetric water content in capillary fringe soils [cm^3-H_2O/cm^3-soil]
θ_T	=	Total soil porosity [cm^3/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [(mg/cm^3-air)/(mg/cm^3-H_2O)]

D_{crack}^{eff} : effective diffusion coeff. through foundation cracks [cm^2/s]

$$D_{crack}^{eff} = D^a \times \frac{\theta_{acrack}^{3.33}}{\theta_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{\theta_{wcrack}^{3.33}}{\theta_T^{2.0}}$$

where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{acrack}	=	Volumetric air content in foundation/wall cracks [cm^3-air/cm^3-total volume]
θ_{wcrack}	=	Volumetric water content in foundation/wall cracks [cm^3-H_2O/cm^3-total volume]
θ_T	=	Total soil porosity [cm^3/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [(mg/cm^3-air)/(mg/cm^3-H_2O)]

Source: ASTM E1739-95

DOMENICO MODEL: DILUTION ATTENUATION FACTOR (DAF) IN THE SATURATED ZONE

Domenico model for multi-dimensional transport with decay and continuous source:

$$\frac{C(x,y,z,t)}{C_o} = (1/8)\ exp\left[\frac{x}{2\times\alpha_x}\left[1-\sqrt{1+\frac{4\times\lambda\times\alpha_x}{v}}\right]\right]\times erfc\left[\frac{\left[(x-v\times t)\sqrt{1+\frac{4\times\lambda\times\alpha_x}{v}}\right]}{2\sqrt{\alpha_x\times v\times t}}\right]$$

$$\times\left[erf\left[\frac{(y+Y/2)}{2\times\sqrt{\alpha_y\times x}}\right]-erf\left[\frac{(y-Y/2)}{2\times\sqrt{\alpha_y\times x}}\right]\right]\times\left[erf\left[\frac{(z+\delta_{gw})}{2\times\sqrt{\alpha_z\times x}}\right]-erf\left[\frac{(z-\delta_{gw})}{2\times\sqrt{\alpha_z\times x}}\right]\right]$$

where:

C	=	dissolved-phase concentration [mg/L]
C_o	=	dissolved-phase concentration at the source (at x=y, $0\leq z\leq\delta_{gw}$) [mg/L]
v	=	seepage velocity [cm/year]
λ	=	first order decay rate [1/year]
α_x	=	longitudinal dispersivity [cm]
α_y	=	lateral dispersivity [cm]
α_z	=	vertical dispersivity [cm]
x, y, z	=	spatial coordinates [cm]
t	=	time [year]
x	=	distance along the centerline from the downgradient edge of dissolved-plume source zone or source well [cm]
Y	=	width of soil source perpendicular to the groundwater flow direction [cm]
δ_{gw}	=	groundwater mixing zone thickness [cm]
DAF	=	$C_o/C(x)$

Source: Domenico, P.A. and F.W. Schwartz, 1990, Physical and Chemical Hydrogeology. John Wiley and Sons, NY, 824 p. (Eqn. 17.21)

At the centerline, for steady-state (after a long time) the concentration can be obtained by setting $y = 0$, $z = 0$, and $x << v \times t$ as:

$$\frac{C(x)}{C_o} = exp\left[\frac{x}{2\times\alpha_x}\left[1-\sqrt{1+\frac{4\times\lambda\times\alpha_x}{v}}\right]\right]\times erf\left[\frac{Y}{4\times\sqrt{\alpha_y\times x}}\right]\times erf\left[\frac{\delta_{gw}}{2\times\sqrt{\alpha_z\times x}}\right] \quad (1)$$

At the centerline, for steady-state, the DAF without decay can be obtained by setting y = 0, z = 0, x << vt, and $\lambda = 0$ as:

$$\frac{C(x)}{C_o} = erf\left[\frac{Y}{4\times\sqrt{\alpha_y\times x}}\right]\times erf\left[\frac{\delta_{gw}}{2\times\sqrt{\alpha_z\times x}}\right] \quad (2)$$

Note: Comparing to ASTM E1739-95, p. 31, where $Y = S_w$, $\delta_{gw} = S_d$, $v = u$, and $C_o = C_{source}$

At the centerline, for steady-state, the DAF with decay can be calculated using Equation (2). In Equation (2), the retarded seepage velocity (v) is calculated as:

$$v = (K \text{ x } i)/(R_s \text{ x } \theta_{TS})$$

where:

K	=	Hydraulic conductivity [cm/year]
i	=	Hydraulic gradient [--]
θ_{TS}	=	Total porosity in the saturated zone [cm^3/cm^3-soil]
R_s	=	Retardation factor in the saturated zone [--]

LF_{SW}: Leaching Factor from subsurface soil to groundwater [(mg/L-H_2O)/(mg/kg-soil)]	C_s^{SAT}: Soil concentration at which dissolved pore water and vapor phases become saturated [(mg/kg-soil)]
$$LF_{SW}=\frac{\rho_s}{[\theta_{ws}+K_s\times\rho_s+H\times\theta_{as}]\times\left(1+\frac{U_{gw}\times\delta_{gw}}{I\times W}\right)}$$ where: ρ_s = Dry soil bulk density [g-soil/cm^3-soil] θ_{ws} = Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3-soil] K_s = $f_{oc}\times K_{oc}$ = Chemical-specific soil-water sorption coefficient for the unsaturated zone [mL-H_2O/g-soil] f_{oc} = Fractional organic carbon content in the unsaturated zone [(g-C)/(g-soil)] H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)] θ_{as} = Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil] U_{gw} = Groundwater Darcy Velocity [cm/year] d_{gw} = Groundwater mixing zone thickness [cm] I = Infiltration rate of water through soil [cm/year] W = Length of source area parallel to groundwater flow [cm] Source: ASTM E1739-95	$$C_s^{sat}=\frac{S}{\rho_s}\times[H\times\theta_{as}+\theta_{ws}+K_s\times\rho_s]$$ where: S = Pure component solubility in water [mg/L-H_2O] ρ_s = Dry soil bulk density [g-soil/cm^3-soil] H = Chemical-specific Henry's Law constant [(mg/cm^3-air)/(mg/cm^3-H_2O)] θ_{as} = Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil] θ_{ws} = Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3- soil] K_s = $f_{oc}\times K_{oc}$ = Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm^3-H_2O/g-soil] Source: ASTM E1739-95

ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION FOR GROUNDWATER RESOURCE PROTECTION

$$\text{Allowable soil concentration at the source}[\text{mg/kg}] = \textit{Target groundwater concentration at the POE} \times \frac{DAF_{POE}}{LF_{SW}}$$

$$\text{Allowable groundwater concentration at the source}[\text{mg/L}] = \textit{Target groundwater concentration at the POE} \times DAF_{POE}$$

$$\text{Allowable groundwater concentration at the POC}[\text{mg/L}] = \textit{Target groundwater concentration at the POE} \times \frac{DAF_{POE}}{DAF_{POC}}$$

where:

POE	=	Point of exposure
POC	=	Point of compliance
DAF_{POE}	=	Dilution Attenuation Factor between the point of exposure and the source
DAF_{POC}	=	Dilution Attenuation Factor between the point of compliance and the source
LF_{SW}	=	Dry soil leaching factor [(mg/L-H_2O)/(mg/kg-soil]

Concentration at POE is expressed in mg/L-H_2O

Additional relationships used in the calculation of allowable soil and groundwater concentration with chemical degradation:

$$\text{First order decay rate}[1/\text{day}] = \frac{0.693}{\textit{Half Life}}$$

$$\text{Retardation Factor for Organics in the saturated zone } (R_s) = 1 + \left(\frac{\rho_{ss} \times K_{ss}}{\theta_{TS}}\right) \qquad K_{ss} = foc_s \times K_{oc}$$

where:

ρ_{ss}	=	Saturated zone soil bulk density [g-soil/cm^3-soil]
K_{ss}	=	Chemical-specific soil-water sorption coefficient in the saturated zone [cm^3-H_2O/g-soil]
K_{oc}	=	Chemical-specific soil-water distribution coefficient for metals in the saturated zone [cm^3/g-C]
θ_{TS}	=	Total porosity in the saturated zone [cm^3/cm^3-soil]
foc_s	=	Fractional organic carbon content in the saturated zone [g-C/g-soil]

STREAM PROTECTION: ALLOWABLE GROUNDWATER CONCENTRATION AT THE POINT OF DISCHARGE

$$C_{gw} = \frac{C_{sw}\left(Q_{gw} + Q_{sw}\right)}{Q_{gw}} - C_{su}\left(\frac{Q_{sw}}{Q_{gw}}\right)$$

Where:

Q_{gw} = Impacted groundwater discharge into the stream [ft^3/day]
C_{gw} = Allowable concentration in groundwater at the point of discharge into the stream [mg/L]
Q_{sw} = Stream flow upstream of the point of groundwater discharge (stream flow rate) [ft^3/day]
C_{sw} = Allowable concentration at the downstream edge of the stream's mixing zone [mg/L]
C_{su} = The COCs' concentration upstream of the groundwater plume discharge [mg/L]

STREAM PROTECTION: ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION AT THE SOURCE & POC

$$\text{Allowable soil concentration at the source}\left[\text{mg/kg}\right] = \textit{Target surface water concentration}\left[\text{mg/L}\right] \textit{ at the POE} \times \frac{DAF_{POE}}{LF_{SW}}$$

$$\text{Allowable groundwater concentration at the source}\left[\text{mg/L}\right] = \textit{Target surface water concentration}\left[\text{mg/L}\right] \textit{ at the POE} \times DAF_{POE}$$

$$\text{Allowable groundwater concentration at the POC}\left[\text{mg/L}\right] = \textit{Target surface water concentration}\left[\text{mg/L}\right] \textit{ at the POE} \times \frac{DAF_{POE}}{DAF_{POC}}$$

Additional relationships used in the calculation of allowable soil and groundwater concentration with chemical degradation:

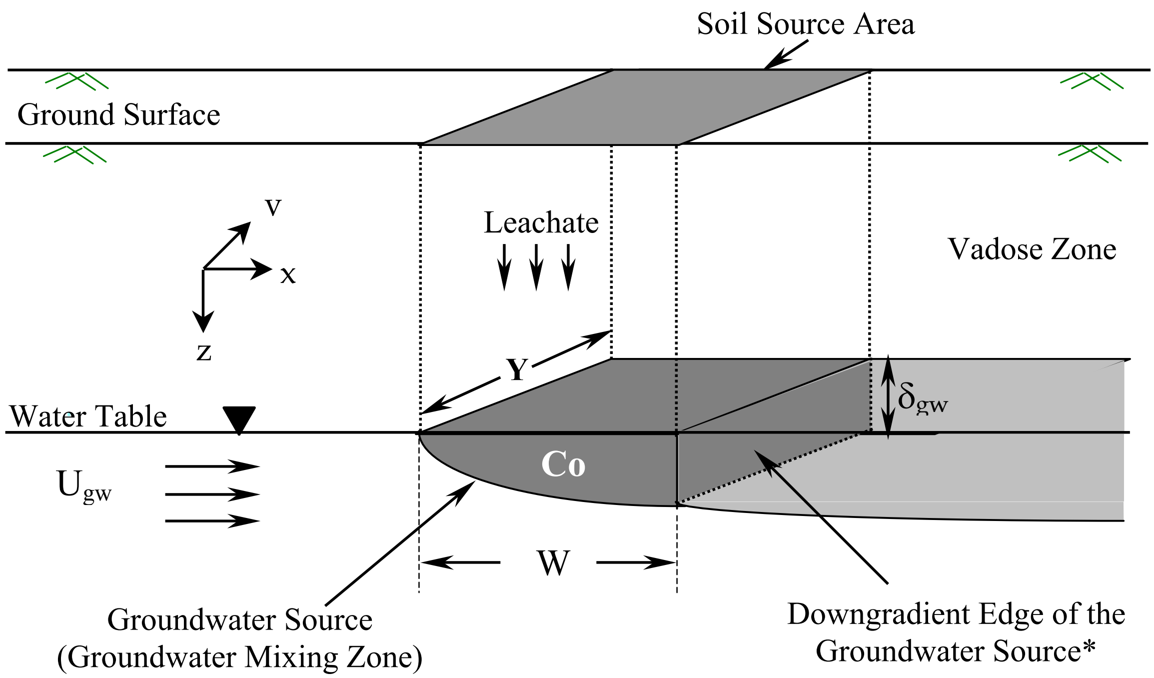
$$\text{First order decay rate}\left[1/\text{day}\right] = \frac{0.693}{\textit{Half Life}}$$

$$\text{Retardation Factor for Organics in the saturated zone } (R_s) = 1 + \left(\frac{\rho_{ss} \times K_{ss}}{\theta_{TS}}\right) \qquad K_{ss} = foc_s \times K_{oc}$$

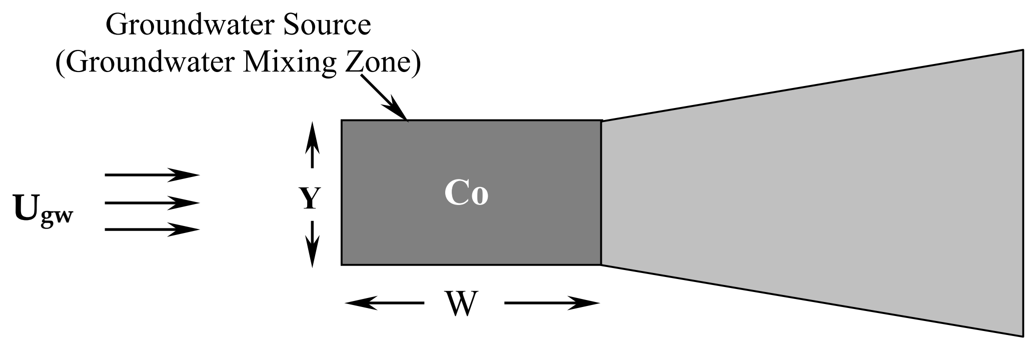
where:

ρ_{ss} = Saturated zone soil bulk density [g-soil/cm^3-soil]
K_{ss} = Chemical-specific soil-water sorption coefficient in the saturated zone [cm^3-H_2O/g-soil]
K_{oc} = Chemical-specific soil-water distribution coefficient for metals in the saturated zone [cm^3/g-C]
θ_{TS} = Total porosity in the saturated zone [cm^3/cm^3-soil]
foc_s = Fractional organic carbon content in the saturated zone [g-C/g-soil]

SCHEMATIC DESCRIPTION OF DOMENICO'S MODEL



SECTION



PLAN

Note:
(* Assumes only vertical leaching, i.e., there is no horizontal spreading in the unsaturated zone.)